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Review article

Sodium symphony: Crafting the future of energy storage with sodium-ion capacitors

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Highlights

- Sodium-ion Capacitors, with their unique security features, stand out as a promising technology for future energy storage.
- The study enhances silicon carbide by addressing metal oxide issues and improving techniques and electrode compatibility for solid-state capacitors.
- A comprehensive discussion of the storage mechanism and construction of Sodium-ion capacitors.
- This study improves metal oxide electrode performance, opening new applications and promoting further research in the field.

Abstract

The high-power density enables rapid charging of energy storage devices. As technology advances, this is increasingly becoming a crucial method to evaluate these systems. Ionic hybrid capacitors are designed to provide more strength and higher energy storage capacity compared to electric double-layer capacitors. By fusing the best features of ionic batteries with electric double-layer capacitors, ionic hybrid capacitors expect to outperform both in terms of energy density as well as power density. Substituting lithium-ion capacitors with sodium-ion capacitors offers cost and material savings, among other advantages. The metal oxide electrodes possess a greater potential specific capacity compared to carbon-based electrodes due to their robust redox reaction. Therefore, they exhibit excellent compatibility with solid-state batteries, commonly referred to as sodium-ion capacitors. In the case of electric double-layer capacitors, the power output gap is reduced due to the high surface pseudocapacitance properties of metal oxide electrodes, which facilitate rapid ion movement. Metal oxides resolved the incompatibility between sodium-ion capacitor electrodes and electric double-layer capacitor counter electrodes. These issues were compounded by the reported drawbacks of metal oxides, such as poor electrical conductivity and significant expansion. To produce high-performance silicon carbides, it is crucial to adhere to appropriate modification techniques and electrode compatibility criteria. This item provides a concise summary of the study conducted on solid-state capacitor electrodes composed of various metal oxides, including the materials utilized. Additionally, there is a comprehensive discussion of the storage mechanism and construction of sodium-ion capacitors. Ultimately, this study provides an extensive understanding and more insights into enhancing the concert of metal oxide electrodes as well as exploring their potential applications, hence promoting further investigation in this field.

Introduction

The existing energy system has resulted in significant challenges, including an energy crisis and environmental damage, due to rapid social and economic expansion [1,2]. Additional solar, wind and tidal energy systems must be implemented to address the current situation and reduce CO_2 emissions [3]. Ensuring a sustainable energy supply requires the development of dependable and effective energy storage technologies, as renewable energy sources have constraints such as intermittent production and low conversion efficiency [4]. Supercapacitors, secondary batteries, and other electrochemical energy storage technologies offer significant benefits in terms of power and energy density [5,6]. Various types of energy storage systems exist; the following are but a few illustrations. Lithium-ion batteries (LIBs) possess difficulties in assessing their rate along with cycle endurance because of the slow movement of ions and significant volumetric pressures that occur throughout both charging and draining operations [7]. Supercapacitors may achieve high densities of power as well as rapid response times due to their ability to quickly accumulate and discharge charges throughout their current state of matter [8].

The role of supercapacitors in electrochemical energy storage is essential. Table 1 and Fig. 1 depict the various categorization techniques used for supercapacitors. The energy density of battery systems may exceed that of traditional electric double-layer capacitors (EDLCs) since the latter lack Faraday processes. The creation of Faraday pseudocapacitors (PCs) has greatly increased the energy density of supercapacitors, thanks to extensive study on the issue [9]. In addition, it should be noted that the basic storing mechanism of LIBs poses obstacles to significant enhancements in power density. This is the type of obstacle that arises. Hence, it is imperative to investigate the structural configurations and fundamental materials of supercapacitors to advance the progress in energy storage gadgets with superior energy and power density [10].

Supercapacitors may be classified into four primary classes based on their energy storage mechanism, depicted in Fig. 2. There are four distinct types of supercapacitors namely redox-electrolyte capacitors (R-ECs), EDLCs, Pseudocapacitors (PCs), and metal ion capacitors (MICs) [11]. These categories are founded on energy storage technology. The point of contact between the electrode and electrolyte is where EDLCs accumulate charge [12]. As a result of this activity, the Helmholtz electric double layer forms between them. The energy storage technology, referred to as EDLC, uses physical storage without the need for chemicals. It is feasible to get a substantial power density and an accelerated kinetic reaction during storage. The use of physical adsorption methods leads to a decrease in energy density [[13], [14], [15], [16]]. Voltage and charge transfer are inherently linked due to their interdependency [17]. PC energy storage requires reversible redox reactions to occur on the electrode surface. These reactions are essential for the transmission of electric charge. Electrochemical reactions exhibit great efficiency due to the ability of ions to easily access redox channels and interlayers. Conventional batteries and personal computers can store energy through surface processes [18]. PCs have the potential to surpass EDLCs in terms of specific capacitance at a certain voltage. Hybrid capacitors have the combined attributes of both PCs and EDLC. Such capacitors augment the acceptable voltage spectrum and amplify the energy as well as power density [19]. Hybrid capacitors consist of two types: R-ECs and MICs. MICs store energy through electrode reactions, while R-ECs utilize electrode materials for energy conversion. Miniature electrolyte systems can exist in two forms: aqueous or anhydrous. Electrolytes provide the foundation of these groups. Lithium-ion capacitors are the most significant MICs for scientific endeavors. In 2001, Amatucci created the first lithium-ion battery using a nano $Li_4Ti_5O_{12}$ anode and an activated carbon (AC) cathode [20]. The scarcity of lithium minerals in the Earth's crust has led to the persistent high costs of lithium salt. The cost of lithium-ion and lithium-current batteries, along with other lithium-related products, has increased due to this phenomenon. Examining MICs devoid of lithium will contribute to addressing future resource apprehensions. According to the periodic table, sodium and lithium are categorized as alkali metals. The electrochemical intercalation behavior of these two elements exhibits similarities. Sodium ion capacitors (SICs) employ sodium ions (Na^+) for energy storage, similar to rechargeable batteries and supercapacitors.

The issue of energy is the foremost concern faced by contemporary civilization. The unregulated exploitation and extensive usage of fossil fuels have led to a significant increase in pollution levels. So, it is necessary to investigate novel, eco-friendly energy storage techniques to satisfy the growing need for electricity and power [22]. Secondary batteries are increasingly used for electric energy storage due to their better efficiency. These batteries are utilized in wind turbines, high-capacity automobile batteries, and portable devices [23]. They have a significant impact on the efficiency of energy utilization in civilization. There is a pressing demand for cost-effective energy storage systems that require a significant amount of resources [24]. Rechargeable batteries are highly efficient for generating energy on a large scale. Rechargeable LIBs have been the dominant force in the energy storage sector since their debut in 1991 [25,26]. This is mainly due to their exceptional